

## New Systems Showing Light-Time Effect

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**Abstract.** Two Algol-type eclipsing binary systems (EW Lyr and IV Cas) have been investigated for period changes. Our study was primarily focused on the light-time effect with alternative explanation by magnetic activity cycles. In the case of EW Lyr we have found third body in the orbit with period about 78 years, amplitude  $A = 0.052$  days and orbital eccentricity  $e = 0.57$ . For IV Cas the long period is 58 years, amplitude  $A = 0.034$  days and zero eccentricity. With these results we are also able to calculate mass functions and minimal masses of these components.

### 1. Introduction

Eclipsing binaries are known as ideal cosmic laboratories for studying the properties of stars. One method is the period analysis of these systems. In some cases there is a possibility of detection of other bodies in these systems using this method. But the  $O - C$  diagrams have to show periodic oscillations with well-defined shapes, sufficiently large amplitudes and adequately long periods. Very short periods have only small amplitudes and the long periods are not well covered with data yet. All these conditions and the accuracy of our data set have to be considered for the limitations of our proposed hypothesis of the light-time effect.

The light-time effect (hereafter LITE), caused by the orbital motion of the eclipsing pair around the barycenter of the multiple system, was explained by Irwin (1959) and its necessary criteria have been listed by Friebois-Conde & Hertzeg (1973) and also by Mayer (1990). Presence of a third body in the system is possible only if the times of minimum, also the secondary ones, behave in agreement with a theoretical LITE curve, the resultant mass function has reasonable value and corresponding variations in radial velocities are measured. During the last decade also a confirmation by astrometry seems to be plausible. But regrettably in both investigated systems (EW Lyr and IV Cas) no photometric or spectroscopic study was performed, so these LITE systems are still only hypothetical, because of no other confirmation of the LITE. But there is still a possible explanation of this variations in minima times by another phenomenon, such as magnetic activity. We discuss this possibility later.

In both cases we have calculated new light elements of the eclipsing pair and also the parameters of the third body orbit. Their  $O - C$  diagrams are shown in the Figs. 1 and 2. The curves represent computed light-time effect caused by the third bodies with parameters given in Table 2 below. The individual primary and secondary minima are denoted by dots and circles, respectively.

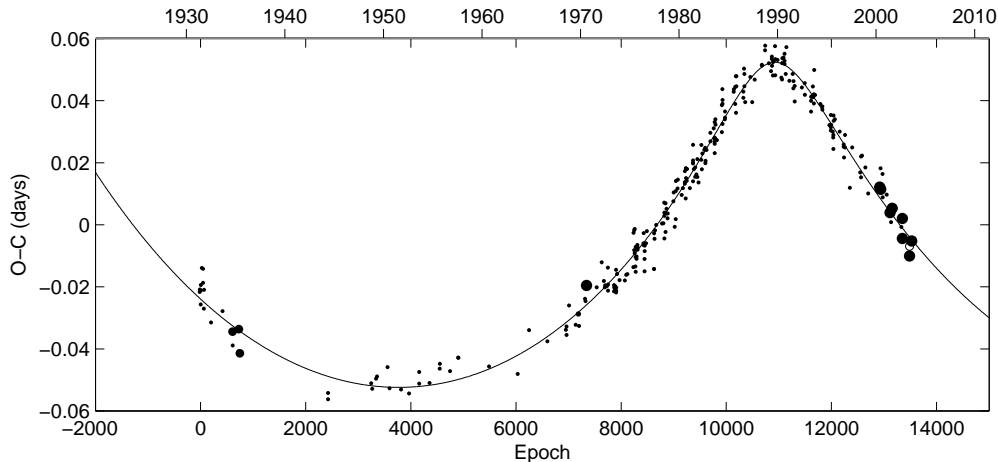


Figure 1. The  $O - C$  diagram of EW Lyr.

Larger symbols correspond to the photoelectric or CCD measurements which were given higher weights in our computations.

For the computation we used the least-squares method. All data were found in published papers. Table 2 presents our results, where  $M_i$  are masses of components,  $p_3$  computed period of the unresolved body,  $A$  semiamplitude of LITE,  $e$  eccentricity,  $\omega$  length of periastron,  $f(M_3)$  computed mass function and  $M_{3,\min}$  minimum mass (for  $i = 90^\circ$ ) of the third body, respectively.

## 2. EW Lyr

EW Lyrae is an Algol-type eclipsing binary discovered by Hoffmeister (1930) and its period changes were recognized in Szafranic (1956). Spectral type was determined as F0 (Brancewicz & Dworak 1980) or A8-9V (Halbedel 1984) with the individual masses about  $1.39$  and  $0.84 M_\odot$  according to Budding (2004). But the values are still not very convincing. Our collection of minimum times (covering more than 70 years) leads to new recomputed light elements

$$\text{Min I} = \text{HJD } 24\,26499.7224 + 1^d 94873888 \cdot E$$

The potential third body orbits the eclipsing pair with a period of almost 78 years and eccentricity  $e = 0.57$ . Its predicted minimal mass would be about  $1.1 M_\odot$ . So in the solution of the light curve, the third light would be measurable, but regrettably no light-curve study of this system was made yet.

We could also discuss so-called Applegate mechanism which causes the periodic variations in the  $O - C$  diagram. At the very beginning we have to accept some assumptions about the basic parameters of the system:  $M_1 = 1.39 M_\odot$ ,  $M_2 = 0.84 M_\odot$ ,  $R_1 = 1.59 R_\odot$ ,  $R_2 = 0.85 R_\odot$ . But these values are taken only from statistical properties of stars of each spectral type, so they are not very convincing. We also assume the separation of the components to be  $a = 10 R_\odot$  and the rate of the differential rotation of the stars  $\Delta\Omega \simeq \Omega_{dr}$ , see Applegate

(1992). With these parameters we are able to determine the properties of the Applegate effect for both components (see Table 1).

But as we can see from the values, this explanation seems to be completely improbable. Especially if we focus on the values  $\Delta L_{\text{RMS}}$  and  $B$ , they are very high and make no sense in our case. Luminosity variations caused by this effect could not exceed the total luminosity of the system and also the value of magnetic field seems to be quite high. So we can clearly conclude that this effect is not presented in EW Lyr.

### 3. IV Cas

IV Cas is an Algol-type eclipsing binary, with spectrum classified as A2. As in the case of EW Lyr, our knowledge about the system parameters is not very satisfactory. From the data we have calculated new light elements

$$\text{Min I} = \text{HJD } 24\,40854.6289 + 0^{\text{d}}.99851644 \cdot E$$

The  $O - C$  diagram in Figure 2 covers one hundred years. Until the 1990s there were a possibility to describe the shape of the  $O - C$  diagram by a quadratic term, so the mass-transfer hypothesis was discussed. But with new accurately measured minima we are nowadays sure about the periodic behavior. We have also neglected the visual minima times measured after 1995. The potential third body was found in the circular orbit of period almost 60 years and amplitude 0.034 days. This gives the value of minimal mass about  $1.16M_{\odot}$ . But as in the case of EW Lyr, we do not have any analysis of a light curve and also any spectroscopic study of this system, so we cannot prove this result.

With the presumptions  $M_1 = 2.6M_{\odot}$ ,  $M_2 = 1.24M_{\odot}$ ,  $R_1 = 2.0R_{\odot}$ ,  $R_2 = 2.22R_{\odot}$  (see Budding 2004), the separation of the components  $a = 10R_{\odot}$  and differential rotation of the stars  $\Delta\Omega \simeq \Omega_{dr}$  we are able to derive the parameters of the Applegate effect (given in Table 1).

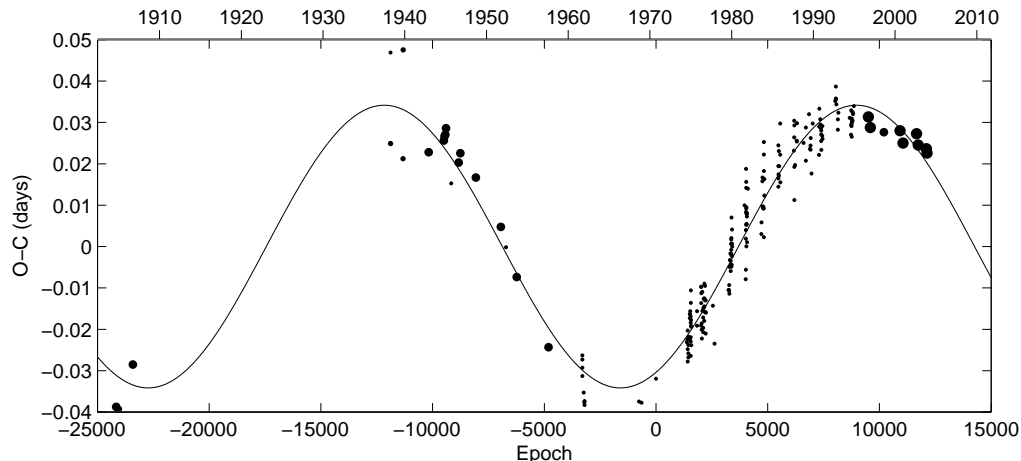


Figure 2. The  $O - C$  diagram of IV Cas.

Table 1. The parameters of the Applegate effect for both stars.

	EW LyrPrim	EW LyrSec	IV CasPrim	IV CasSec	Units
$\Delta P$	1.95	1.95	0.88	0.88	s
$I_{\text{eff}}$	7.55	7.80	33.4	19.6	$10^{53} \text{ g} \cdot \text{cm}^2$
$\Delta J$	34.6	5.65	14.9	2.48	$10^{48} \text{ g} \cdot \text{cm}^2 \cdot \text{s}^{-1}$
$\Delta \Omega$	229	36.2	22.3	6.32	$10^{-7} \text{ s}^{-1}$
$\Delta E$	1580	40.9	66.7	3.14	$10^{42} \text{ erg}$
$\Delta L_{\text{RMS}}$	520	13.4	29.5	1.4	$L_{\odot}$
$B$	59.9	16.2	23.9	8.3	kG

But as we can see from the values, this explanation seems to be again improbable on primary component, but we could discuss, if affects the secondary or not. For example the value  $\Delta L_{\text{RMS}}$  seems to be rather high, but if we compare it with the luminosity of the secondary, we almost satisfy the condition  $\Delta L_{\text{RMS}}/L \lesssim 0.1$  introduced by Applegate (1992), because we get  $\Delta L_{\text{RMS}} \simeq 0.18L$ . So we could discuss the probability of period modulation in IV Cas caused by the magnetic activity cycles on secondary component. This possibility remains to be studied and confirmed to the future.

Table 2. The resulting LITE parameters for investigated systems.

Name of star	Spectrum	$M_1$ [ $M_{\odot}$ ]	$M_2$ [ $M_{\odot}$ ]	$p_3$ [years]	$A_3$ [days]	$e_3$	$\omega_3$ [deg]	$f(M_3)$ [ $M_{\odot}$ ]	$M_{3,\text{min}}$ [ $M_{\odot}$ ]
EW Lyr	A8-9V	1.39	0.84	77.83	0.0524	0.574	86.4	0.123	1.11
IV Cas	A2	2.60	1.24	57.78	0.0342	0.001	5.8	0.062	1.16

#### 4. Conclusions

We have derived new LITE parameters for two eclipsing binaries by means of the  $O - C$  diagram analysis. We have suggested the light-time effect for explanation of the period variation. We have also mentioned a probability of presence of magnetic activity cycles, which could modulate the period. In case of secondary component of IV Cas this hypothesis should also be in stage, but we have not enough data to make a final decision. So the consequence is, that for the confirmation of presence of the LITE in these systems, we need further detailed photometric, spectroscopic or astrometric study of these binaries.

#### References

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